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PROJECT EXPLORER, GAS #007
STS-61C, COLUMBIA FLIGHT

MARCE DATA EVALUATION

BY

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ABSTRACT

The GAS #007 Project Explorer Experiment data recorded and radio downlinked by the Marshall Amateur Radio Club Experiment (MARCE), the first Get Away Special radio experiment, are compared and evaluated.

A compatability assessment, of the student experiments and the MARCE power, control and data systems, during the STS-61C Columbia flight in January 1986 is presented. Analysis of the GAS container's thermal environment, located near the center of the GAS Bridge is discussed.

BACKGROUND

GAS #007, here after called G #007, was sponsored by the Alabama Space and Rocket Center, Huntsville, Alabama and the Alabama/Mississippi section of the American Institute of Aeronautics and Astronautics (AIAA). The MARCE design, development, testing, coordination, volunteers, support and flight history are described in the GAS Experimenter's Symposium Proceedings[1,2,3]. The G#007 measurements consisted of six temperatures, one each main battery voltage and current and the container pressure. Eight status conditions were stored in the MARCE memory as well as downlinked (DL) by amateur radio, however, the status data was intended for information only. All of the DL data, received from the world wide amateur radio groundstations, has been converted to engineering units, formatted and plotted. The on-board stored memory data was more difficult to reduce and took much longer. This on-board data has now been converted to engineering units, formatted and plotted and analysis is nearly completed. This paper documents the assessment of the flight results.

EXPERIMENT MEASUREMENTS

G #007 consisted of three student experiments and MARCE. Experiment #1, Solidification of Alloys, contained two Ovens. Oven #1 housed Lead (30%)/Antimony, requiring 400^{o} C for melting. Oven #2 contained Copper /Aluminum (4.5%), requiring 700^{o} C for melting. MARCE measurements T1, for Oven #1 and T2, for Oven #2 were assigned as overtemperature measurements and for safety controls, whenever Exp. #1 was operating. T1 and T2 settings were designed to give an off-scale reading of 20^{o} C, unless higher temperatures were encountered. The 700^{o} C, in Oven #2, caused the temperature to rise to 38^{o} C on the oven's external surface, as shown in Figure 3. Oven #1, at 400^{o} C, resulted in the external surface to reach only 18^{o} C. T1 then is a straight line at 20^{o} C.

Exp. #2, Plant Physiology, contained MARCE measurement T3 to trace the seed/root growth chamber temperature. The main battery powered the 2.8 watt heater unit, located around the inside of the well insulated package. T3 was for measurement only, no control. A thermostat was set to actuate at $+17^{o}$ C, whenever G #007 power was applied.

Exp. #3 contained a 6 ml, 0.3 M solution of potassium tetracyonaplatinate, for crystal growth. MARCE measurement T4 was set inside the insulated growth chamber. Six "D" cells powered the 2.7 watt heater. The thermostat was set to activate at $+10^{o}$ C, to conserve power.

Exp. #4, MARCE, contained the remaining measurements, which were important to all experiments. T5 measured the internal container thermal environment. It was attached to the outside case of the 28 VDC to 7.5 VDC converter. T6, the battery internal temperature measurement, was installed by Eagle Picher, the Solid Rocket Booster (SRB) battery manufacturer. Thermister T6 was designed for measuring 0^{o} C to 60^{o} C and was located in the potting near the center of the battery, which provided good thermal conduction. Chris Rupp[4] designed a safety control and temperature monitor circuit for the battery thermister. The safety control circuit fed GAS malfunction circuit #2. V1 was the SRB battery voltage measurement and I1 was the SRB battery current measurement. P1 measured the one-atmosphere Gaseous Nitrogen container pressure.

DATA STORAGE AND DOWNLINKS

MARCE stored the nine measurements and the eight status conditions, at the start of every 10 minutes. The MARCE memory did not store the Exp. #1 data, since the Exp. #1 data system was designed to collect and store all of it's own data. The second and third radio downlinks (DLs), during Exp. #1 operations, contained the eight Exp. #1 temperatures (4 for each oven), central daylight time and five status conditions. The radio transmissions, at the start of each minute, during the second and third DLs, provided excellent near real time data, for operational performance assessment of all experiments and G #007 housekeeping.

During the three 8-hour DLs, 1440 data messages were transmitted from Columbia, of which 485 (34%) were recorded by groundstations. The audio cassette recordings, received by the Marshall Amateur Radio Club (MARC) were verified. The MARCE memory stored 144 data messages during the 24 hours of downlinks. The results show that 341 more messages were received in the DLs than were stored in the MARCE memory, during the three radio DLs. 327 of the 485 DL messages were available, at MARC, before the flight package arrived in Huntsville, on February 5, 1986. The added DL messages allowed a significant number of data points, more than the MARCE memory provided. Major experiment operations were scheduled during the second and third 8-hour DLs. The added DL messages revealed near real time experiment operations and housekeeping status, that were not available from the on-board memory.

POWER SYSTEM ASSESSMENT

The power consumed by G #007 was near 37 ampere hours, for the 110 hours and 20 minute power-on time, giving more than 26% reserve. Included is the unscheduled 8-hour DL, which consumed 2.52 AHr. Without the added 8-hour DL, the power reserve would have been more than 33%. The battery voltage V1, in Figure 1, shows no degrading, with time. The extremely low temperatures, plotted in Figure 2, likewise do not degrade the V1 voltage level, during any part of the mission. The I1 current levels were as expected for the various loads. The reserve is based on the specified 50 AHr capacity. The SRB batteries have shown capacities of up to 65 AHr, at 28 VDC. More battery power was available, since the software and computer "cut-off" was set at 22 VDC. This indicates that much more heater power was available and added heater units should have been installed, for cold contingencies. STS-61C was an extra cold mission, as indicated by Figure 2. No lower than -5^{o} C was expected.

G #007 power was turned "OFF" by the Columbia crew at 3:19:31:09, (D:H:M:S) STS-61C Mission Elapsed Time (MET), and 079:31:09, H:M:S, (G #007 MET), on January 15, 1986. The purpose was to prepare Columbia for a landing at KSC, on January 16, 1986, before an impending storm would hit KSC. However, due to bad weather the next morning, Columbia received a mission extension.

G #007 was turned "ON", for a second time at 4:05:14 (STS-61C MET), 079:40 (G #007 MET), on January 16, 1986, after a G #007 power "OFF" of 9 hours and 43 minutes. The transmitter was to be turned "ON" for DL #4, but Relay B was not activated, as shown by I1, in Figure 1.

The second G #007 power "ON" lasted for 13 hours, when the G #007 power was turned "OFF" at 4:18:14 (STS-61C MET), 092:40 (G #007 MET), for Columbia's expected landing at KSC. The next day, the mission was extended again, for weather.

G #007 power was turned back "ON" for a third time at 5:00:47 (STS-61C MET), 092:50 (G #007 MET). DL #5 did occur, as shown by I1, in Figure 1. The third G #007 power "ON" lasted for 17 hours and 18 minutes, when G #007 power was finally turned "OFF" at 5:18:25 (STS-61C MET), 110:20 (G #007 MET), for the landing of Columbia at KSC, on January 18, 1986 at 6:59 a.m. CST, after a 6 day, 2 hour, 4 minute mission (146 hours, 4 minutes), of which G#007 power was "ON" 110 hours and 20 minutes.

DATA AND CONTROL SYSTEM ASSESSMENT

All MARCE measurements, software controls, relays and the data system performed as planned, during the STS-61C flight[4]. Likewise, all three student experiments responded to the MARCE controls as planned.

The thermister calibation was verified during the G #007 thermal test. Strip chart recorders monitored the total testing of both the hot and the cold development/qualification testing. A laboratory thermometer, with external readout, provided the temperature calibration readings for the test chamber environment. Prior to the cold test, a 4 hour dwell at 0^{o} C, stabilized the system. The test started with 24 hours at 0^{o} C, followed by 8 hours at -5^{o} C, during which time the Exp. #1, Oven #2 was operated. Next was 12 hours at -10^{o} C, 12 hours at -15^{o} C, followed by a 12 hour excursion to 0^{o} C.

The hot test was preceeded by 0^{o} C dwell for 4 hours. The test consisted of 8 hours at 20^{o} C, 8 hours at 35^{o} C and 8 hours at 45^{o} C, during which time Oven #1 was operated. This was followed by 4 hours at 22^{o} C.

The cold temperature (-15^{o} C) revealed that added heater capacity was required. Heater capacities were increased three-fold in both Exp. #2 and #3. The transmitter was operated at the start of every 4 minutes.

The data and control system and all measurements operated as planned, during the hot and cold testing. The Digitalker^{TM} output was plugged into a cassette recorder and activated by the transmitter "ON" signal, during the thermal tests.

The DL data and the thermal test data showed excellent correlation. The thermisters were all space qualified and proven reliable and repeatable. The pressure sensor (P1), used in the Space Processing Applications Rocket Project (SPAR) flights, proved to be reliable.

The control and sequencing, of the experiments, by the crew and by the microprocessor, during the mission, operated as planned, as did the six relays. The low gravity experimentation, during the crew sleep periods proved to be optimum. The Linear Triaxial Accelerometer measurements made by the Material Science Laboratory-2 (MSL-2), on STS-61C, showed that the quitest of each 24 hour day was during the crew sleep periods.

COLUMBIA ORBIT ATTITUDES ASSESSMENT

According to the STS-61C "AS FLOWN" attitude timelines, G #007 "power-on" was applied at 0:11:50 (day:hour:minute), STS-61C (MET).

Columbia had completed the IMU maneuver and was in Inertial Hold (IH). 30 minutes later, Columbia was put in the Solar Inertial (+YSI), Nose South Pole attitude and remained in the +YSI attitude for 10 hours, or through the rest of the 8-hour DL. At 0:18:53 STS-61C MET, 007:10 (G #007 MET), the radio relay from MARCE to the AMSAT OSCAR (AO-10) satellite and down to Guam Island was completed. Joel, KG6DX, recorded the relayed voice message. This was the first Amateur Radio relay (TDRS mode) in the GAS program and in Amateur Radio Communications. It is apparent that this secondary objective of MARCE would not have been possible, if the Columbia cold APU problem had not occurred.

The second 8-hour DL started at 1:07:55 and ended at 1:15:54, Columbia MET, at the nominal IH of 0^{o} Pitch, 270^{o} Yaw and 180^{o} Roll (-ZLV Nose North).

The third 8-hour downlink started at 2:06:42 Columbia MET. The IH attitude of 21.80^{o} Pitch, 332.01^{o} Yaw and 180^{o} Roll held until 2:07:45, when the IMU Pair C2 event changed the Columbia attitude to 283.00^{o} Pitch, 76^{o} Yaw and 50^{o} Roll. At 2:08:08 MET, Columbia was changed to -ZLV Nose North, with 0^{o} Pitch, 270^{o} Yaw, and 180^{o} Roll, Local Vertical Local Horizontal (LVLH), until the end of DL #3, at 2:14:41 Columbia MET.

The voice messages received in DL #1: 46 of 480 sent; DL #2: 174 of 480 sent; and DL#3: 265 of 480 sent indicates that the best Orbiter attitudes, for ground station reception may have occurred during DL #2 and DL #3.

Figure 2 reveals that the Orbiter attitude has the predominate influence on the container thermal environment, with experiment power having significant thermal control. The only constant temperature period shown is between 70 and 80 hours. This was prior to the first landing attempt and just prior to the first G #007 "power-off".

GAS BRIDGE THERMAL ENVIRONMENT

G #007 forward position, near the center of the GAS Bridge, was requested for minimum interference to other (than GAS) payloads and for an optimum radiation pattern from the MARCE antenna. During a normal earth facing mission, this location would appear to provide a reasonably moderate thermal environment. Comparing a longeron-sill location with the center of the bridge indicates a warmer temperature on the aft sill, based on Orbiter and GAS Development Flight Instrumentation temperature measurements.[5] The abnormal flight attitudes of STS-61C and the thermal isolation, near the center of the bridge, are apparent reasons for the colder than expected temperatures (See Figure 2) measured on G #007.

The Chemglaze white surface, on the non-insulated G #007 Lid has an alpha/epsilon ratio of 0.4 compared to 0.1 for Silverized Teflon. The Chemglaze could provide a temperature rise of about 180^{o} F compared to the Silverized Teflon, with a one Solar Constant input. Since the payload bay did not face the sun, such a temperature rise did not occur. Instead, the +YSI attitude caused an unexpected cold environment, during DL #1, as shown in Figure 2.

During the 8-hour DL #1, Exp. #2, #3 and #4 contributed 16 Watts. When the transmitter is not ON, Exp. #2, #3 and #4 contributed 6.8 Watts. A comparison of Figures 1 and 2 shows that power contributed by the experiments had little thermal influence, when Orbiter attitude points away from the earth and the sun.

During the DLs #2 and #3, Exp. #1 contributes 75 Watts, for about 18 minutes (Oven heat-up), followed by a 30 minute regulation using 45 Watts. For the remainder of the six hours, a 15 Watt load provides heat for the canister. During all other times that the transmitter and Exp. #1 are not "ON", 6.8 Watts is the load.

The only time that the thermostat cycled on Exp. #2 was immediately following DL #2, as shown in Figure 2. This is apparently due to the combination of heat from Oven #2, Exp. #4 transmitter system, a favorable Columbia attitude and Exp. #2 heater. Figure 3 shows that the Oven #2 external surface heat-up (T2) occurs prior to the highest temperatures reached, in the G #007 container. The SRB battery temperature, shown in Figure 2 (T6), was colder than the other experiment assemblies, during the warm part of the cycles. T6 shows the thermal lag of the battery. This is apparently due to the large battery mass of 45 pounds.

SUMMARY AND CONCLUSIONS

The excellent operation of the MARCE power, data, instrumentation and measuring systems and the DL data provided the MARC team with a basis to assess the experiments performance. Strip heaters should have been installed around the inside walls of the insulation, in each experiment chamber. Exp. #3 should have been better insulated and should have used the main power (SRB battery). These changes could have made a significant difference in the operation of Exp. #2 and #3. Exp. #3 solution would probably not have frozen and a more conducive environment would have been realized for the root growth system in Exp. #2. Pressure P1 responded to the temperature changes, as shown in Figure 2.

A graphic example of GAS container thermal variations, with changes in Exp. power, is shown in Figure 2. During DLs #2, #3 and #5, T5 rises faster than T3, T4 and T6. T5 is mounted on the DC to DC converter, which has it's heaviest load during downlinks. Exp. #2, with the only operational heater, shows by T3, the dramatic drop with no heater power. All temperatures rose when power was reapplied. T6 saturated at -9.8 ^{o} C, due to the SRB battery thermister design for measuring no lower than 0^{o} C. Container location, especially on the GAS bridge, requires special thermal considerations.

The GAS #007 MARCE temperature measurements reveal that heaters are required for experiments that are sensitive to cold temperatures. Special insulating measures are necessary, including the GAS lid, assembly mounting isolators, and the inside of each assembly.

References:

1. MARCE, Edward F. Stluka. Pg. 69, NASA Conference Publication 2324, 1984.
2. Project Explorer GAS #007, MARCE, Edward F. Stluka. Pg. 73, NASA Conference Publication 2401, 1985.
3. STS-61C Columbia Final Report (MARCE), Edward F. Stluka. Pg. 87, NASA Conference Publication 2438, 1986.
4. MARCE Post Flight Analysis, Charles C. Rupp. Pg. 149, NASA Conference Publication 2438, 1986.
5. Temperature Data From Selected GAS Flights, Dan Butler, GSFC, GAS Symposium 3, October 7, 1986.

STS-61C GAS #007 MARCE MEMORY DATA

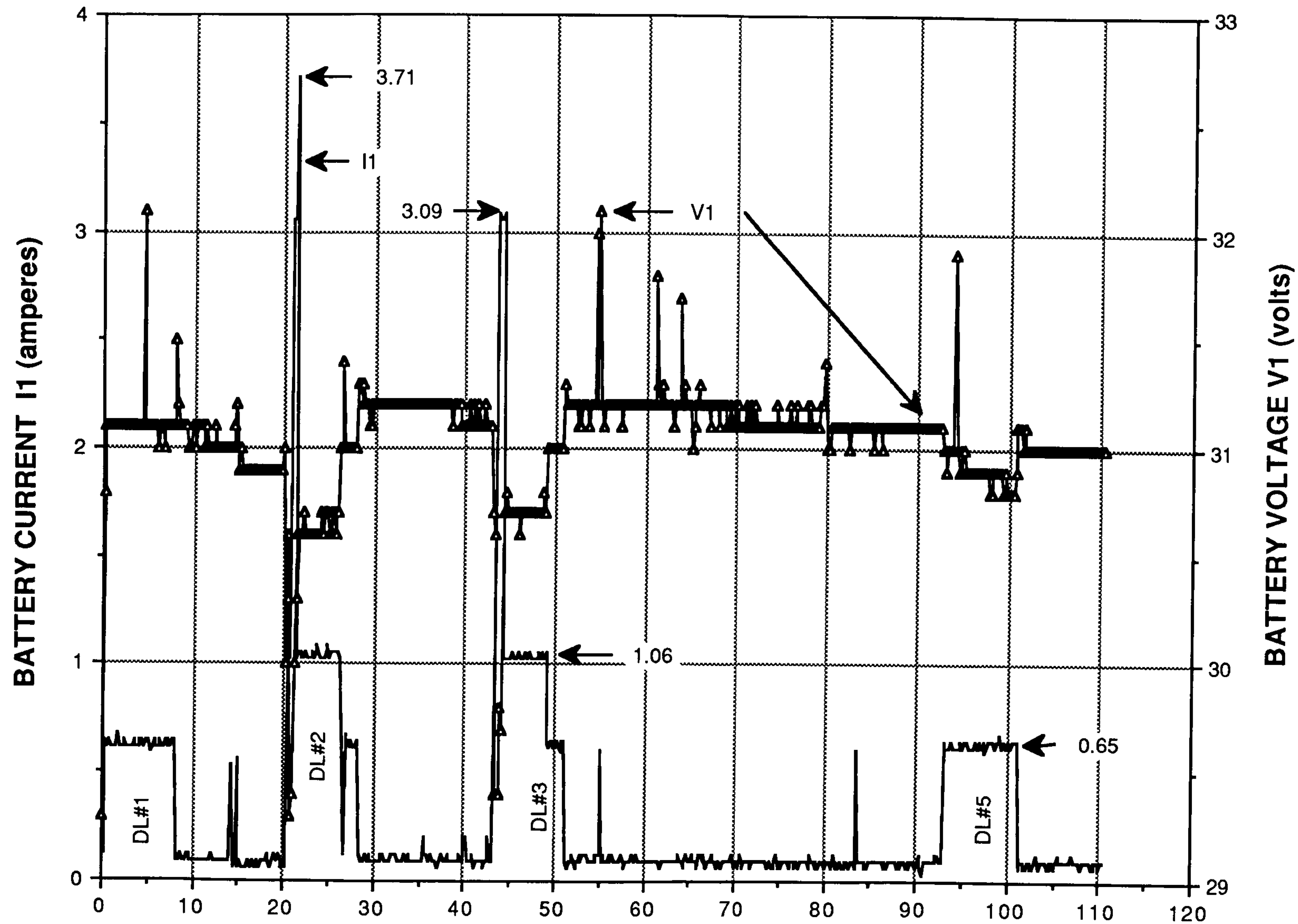

FIGURE 1

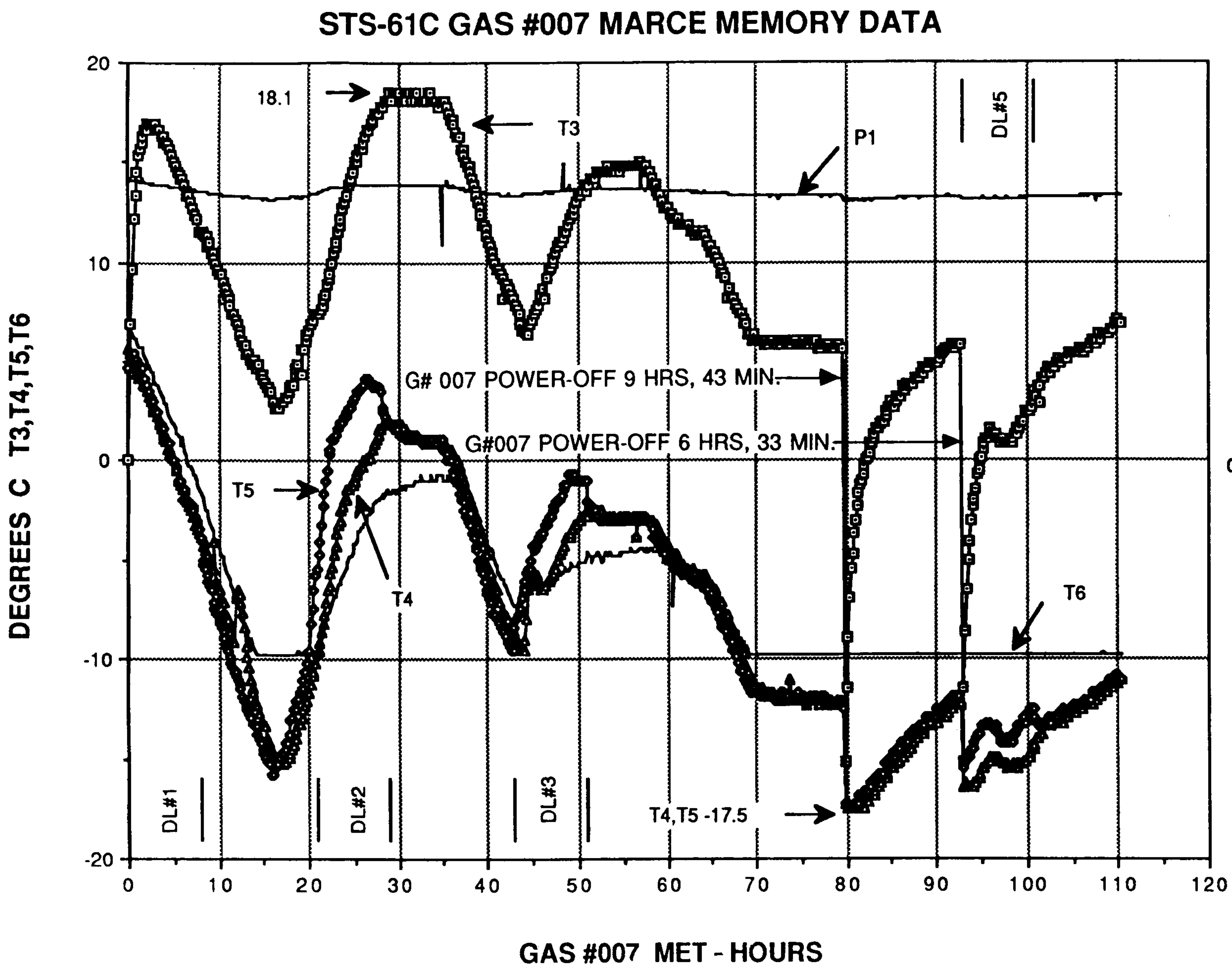
STS-61C GAS #007 MARCE MEMORY DATA
18.1
T3
P1
DL#5
G# 007 POWER-OFF 9 HRS, 43 MIN.
G#007 POWER-OFF 6 HRS, 33 MIN.
T5
T4
T6
DL#1
DL#2
DL#3
T4,T5 -17.5
DEGREES C T3,T4,T5,T6
PRESSURE P1 (psia)
20
10
0
-10
-20
16
8
0
0
10
20
30
40
50
60
70
80
90
100
110
120
GAS #007 MET - HOURS

FIGURE 2

STS-61C GAS #007 MARCE MEMORY DATA

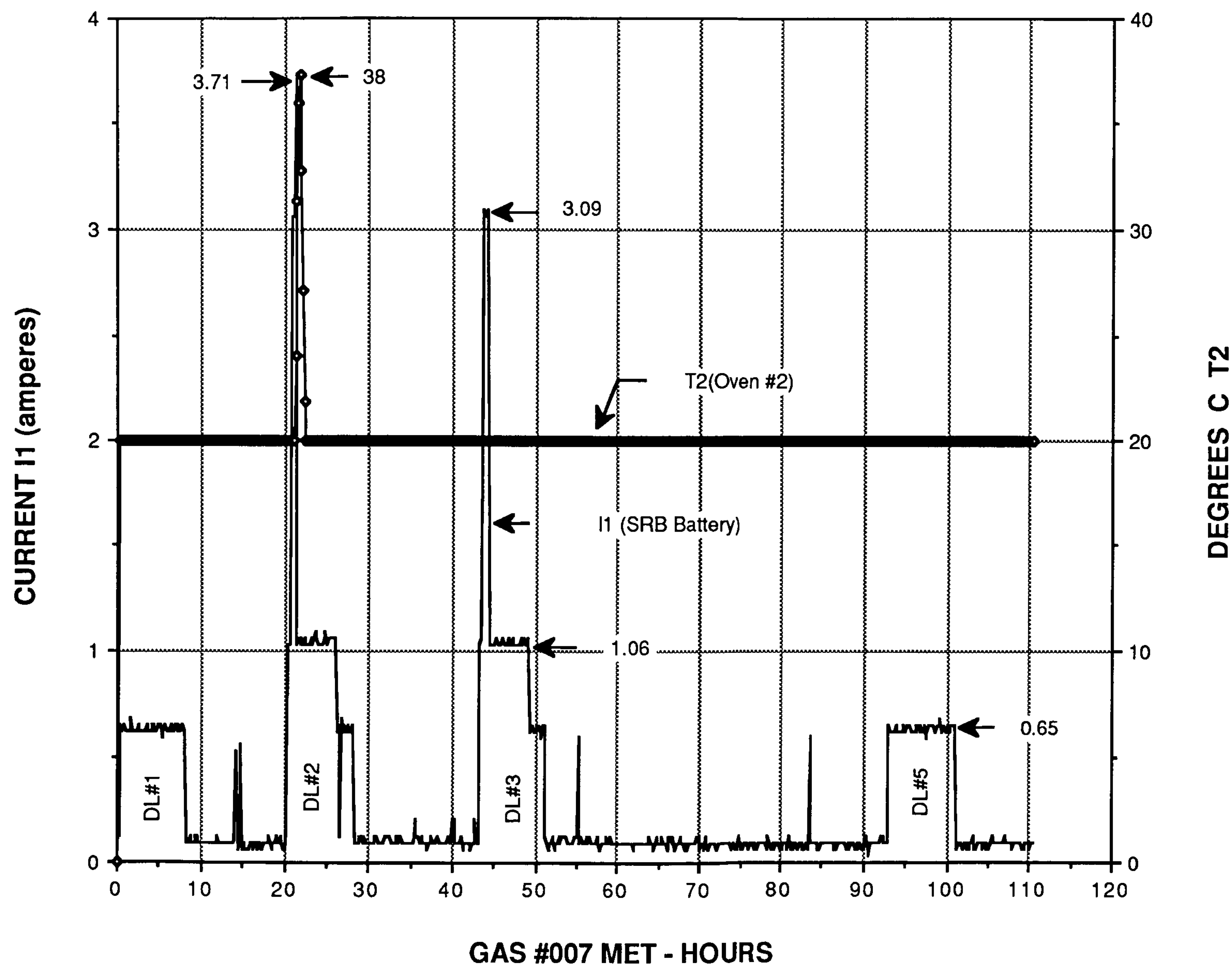

FIGURE 3